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Earth's Thermal Radiation Balance

Preliminary Results from Explorer VII

The following material is based on a more-detailed report by V. E. Suomi, of the University of Wisconsin. The parent report appeared in NASA Technical Note D-608, Juno II Summary Project Report: Volume I, Explorer VII Satellite, *July 1961. The next issue of the* Bulletin *will contain a report on more-recent analyses of the Explorer VII radiation-balance data.*

Preliminary analysis of data obtained by the radiation-balance experiment aboard Explorer VII during the satellite's first eight months in orbit appears to indicate the existence of large-scale patterns of outward flow of radiation from the earth as well as a relationship between these patterns and large-scale weather features of the lower atmosphere. This experiment, one of five major IGY experiments aboard Explorer VII, was conducted under the direction of V. E. Suomi, University of Wisconsin.

Explorer VII (Fig. 1), carrying the largest and most diversified payload of all IGY satellites, was launched on October 13, 1959. (See *Bulletin No. 29* for further details about the satellite and its experiments.) The orbit achieved was almost exactly as planned, with perigee at approximately 555 km and apogee at approximately 1090 km (about 345 and 675 statute miles, respectively); inclination 50°; and period about 101 minutes. This orbit is expected to give the satellite a lifetime of 20 years from launch. The radiation-balance experiment continued until August 19, 1961, when use of new data was discontinued because enough had already been accumulated to satisfy the requirements of the experiment.

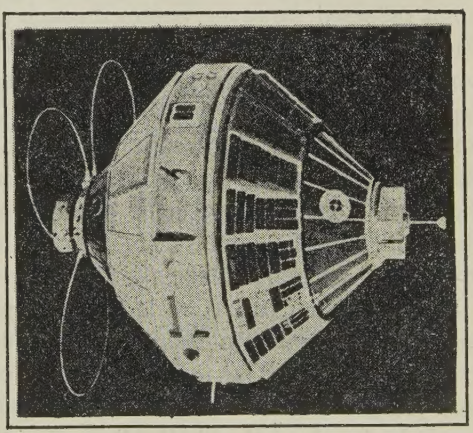


Fig. 1. *Explorer VII (1959 Iota). This was the largest and most diversified of the US-IGY scientific satellites.*

General Background of Radiation-Balance Studies

The value of the sun's radiant energy at the mean distance of the earth's orbit is 2.00 calories/cm^2/minute—the solar constant. The earth intercepts the sun's radiation as a disk and re-radiates it as a sphere; thus, if the earth were a perfect absorber, the average loss per cm^2 at equilibrium would be one fourth the solar constant, or 0.5 calorie/cm^2/minute. The earth's surface is not a perfect absorber, however, and in addition, it is covered with an atmosphere in which part of the solar energy is reflected by scattering. That portion scattered toward the earth is seen as the blue sky.

Clouds, which act much as highly reflecting shutters, exercise the most important variable control on the amount of sunshine reaching the earth's surface. A small part of the sunlight is absorbed by gases in the atmosphere, principally water vapor and ozone. Most solar radiation that is not reflected, however, passes through the atmosphere to the earth's surface, the amount absorbed per unit area of surface depending on the sun's zenith angle and the surface properties. The oceans, for example, absorb about 95% of the radiation reaching them, while polar snow fields absorb only about 10%. Most land surfaces range between these extreme values.

Reflected solar radiation is lost to space and never enters into the global thermodynamic system. The remaining solar energy is absorbed mainly at the earth's surface, which acts as the "boiler lining" of the giant heat engine that drives the atmosphere and causes its motions. The solar input to each unit area of the earth's surface depends on latitude, time of year, and state of the atmosphere above. The effects of latitude and season on the incoming solar energy are well known, but atmospheric effects, especially over large parts of the earth for which weather observations are unavailable, can only be estimated.

Our understanding of the global distribution of the loss of long-wave energy to space is even less well known. Water vapor, carbon dioxide, ozone, and other minor gases in the atmosphere selectively absorb the long-wave energy radiated from the earth's surface and from other layers of the atmosphere, thus creating a very complex "greenhouse effect." The long-wave loss from the top of the atmosphere is three to four times as great as the net long-wave loss at the earth's surface. The atmosphere, then, acts as the principal heat sink whereas the earth's surface is the main heat source.

The long-wave heat loss from the atmosphere can be calculated when the vertical distribution of temperature and infrared radiation absorbers are known; such calculations have already been carried out by a number of workers.

These calculations are handicapped, however, by lack of complete global data on the vertical distributions of temperature and absorbers and, in particular, on the lack of adequate middle- and upper-air cloud-cover data. Until recently, meteorologists have been limited to viewing clouds from below and observing relatively small cloud areas at a time. Despite the observational shortcomings, these studies have clearly shown that parts of the earth are in radiation imbalance.

The tropics receive more energy from the sun than they lose by long-wave radiation to space. Conversely, the polar regions lose more energy to space by long-wave radiation than they gain from the sun. Since, on the average, the tropics are not warming and the polar regions are not cooling, the excess of heat in the tropics and the deficit in polar regions are balanced by poleward transport of heat by the atmosphere and the ocean currents. This poleward heat transport is a fundamental modifier of the world's weather.

These radiation balance studies assume that the earth as a whole is in radiational equilibrium with space, i.e., the total heat gain from the sun is just balanced by the loss to space. However, without qualifica-

tion, particularly with respect to periods considerably in excess of a year or extending to tens of years, this assumption would imply the lack of climatic change. The atmosphere does not have a large heat capacity to smooth out temporal imbalances. One worker has calculated, for example, that a change of only 1% in the amount of incoming solar energy would, if applied only to the atmosphere, cause a world-wide air-temperature change of 6°C (about 11°F). The oceans, on the other hand, have a much greater ability to store heat or provide the excess or deficit. A 1% change in the annual heat budget would change ocean temperatures only a few tenths of a degree in the surface layers and probably only a few thousandths of a degree at greater depths.

A fundamental question concerning the heat balance of the earth is whether there is a self-regulating mechanism. Such a mechanism might work as follows, for example: an increase in net global energy might cause more evaporation from the oceans, producing more clouds which would, however, give less solar input; this might then decrease evaporation, causing production of fewer clouds and resulting in greater solar input, and so forth. The Explorer VII radiation experiment cannot provide a definite answer to this question since it could not obtain observations from the entire earth and, moreover, the orbit was not the best for this purpose; nevertheless, such satellite measurements are believed to be significantly more reliable than those of the past and thus represent a further step toward reaching an answer.

Instrumentation

The radiation sensors used in Explorer VII consisted of hemispheric radiation receivers, the equilibrium temperatures of which were measured by variable resistance elements, or thermistors. Sensor temperatures were telemetered to the receiving stations on earth. Then, by means of heat balance equations, the fluxes, or radiation currents, of both incoming and reflected solar radiation, and of terrestrial re-radiation could be computed from the observed sensor temperatures.

In this instrument system, four thin, hollow, silver hemispheres are mounted on

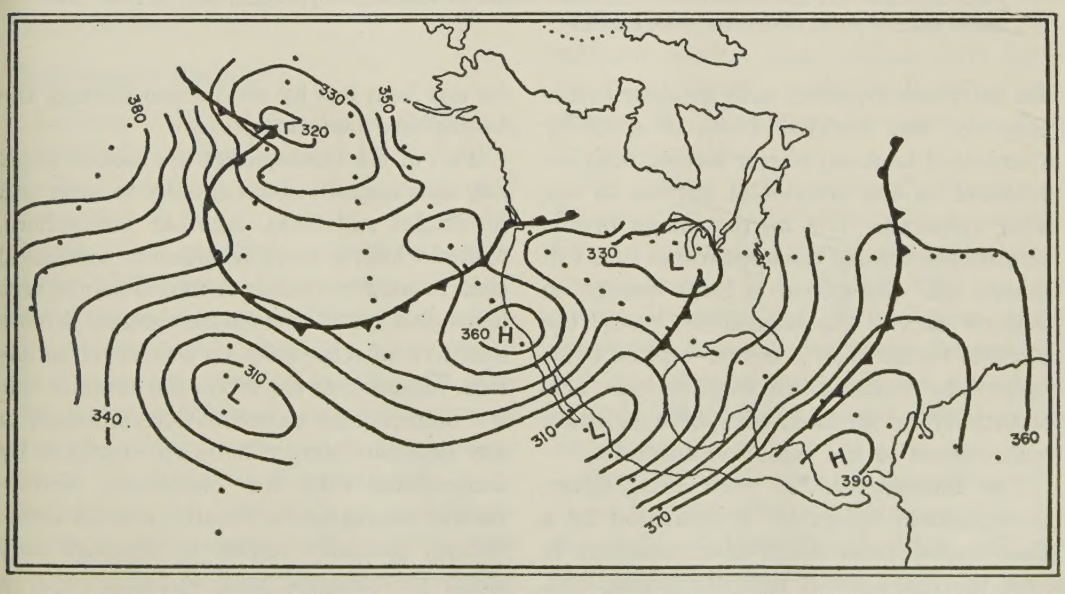


Fig. 2. *Long-Wave Radiation Loss from Northern Western Hemisphere, December 2, 1959, as Determined from Explorer VII Measurements. Radiation values in calories/cm²/minute; dotted lines represent orbital path. (Compare with Fig. 4.)*

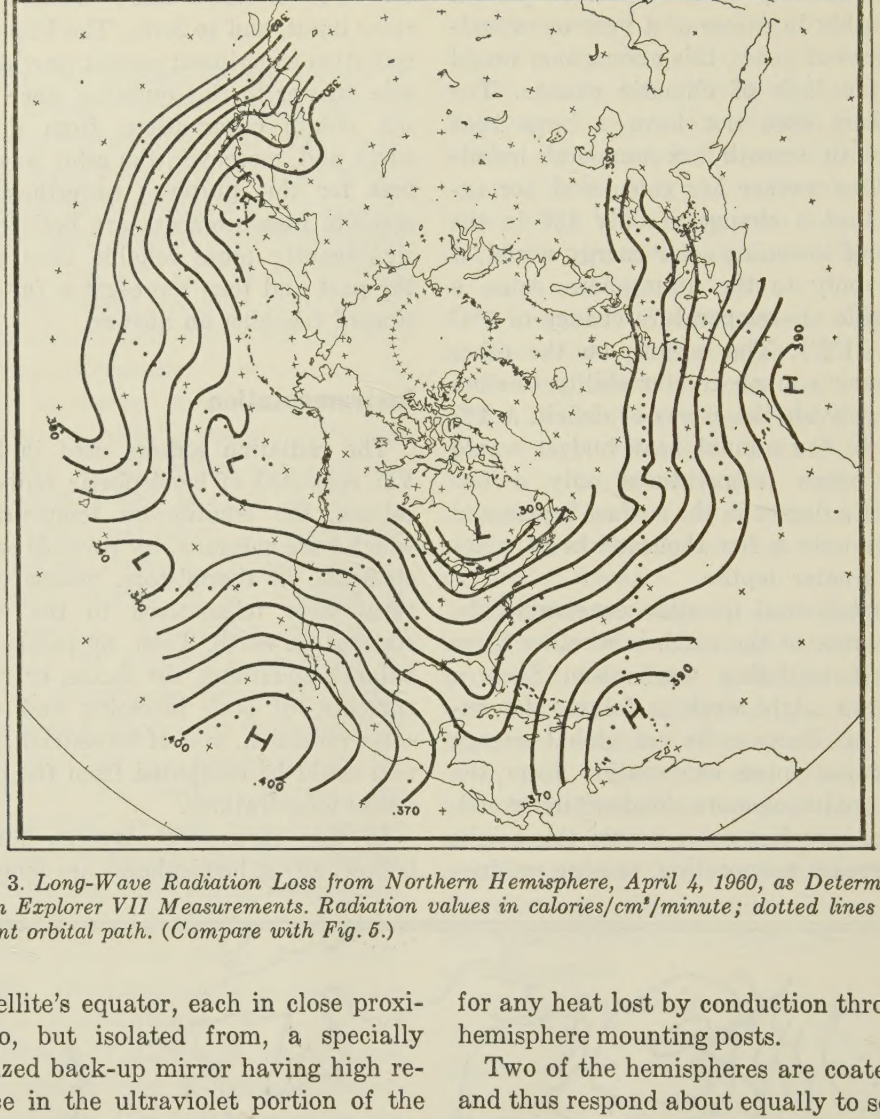


Fig. 3. *Long-Wave Radiation Loss from Northern Hemisphere, April 4, 1960, as Determined from Explorer VII Measurements. Radiation values in calories/cm²/minute; dotted lines represent orbital path. (Compare with Fig. 5.)*

the satellite's equator, each in close proximity to, but isolated from, a specially aluminized back-up mirror having high reflectance in the ultraviolet portion of the solar spectrum. The mirror image of the hemisphere creates the appearance of a full sphere, and the mirror is large enough so that no part of the hemisphere "sees" the satellite itself. Such a mirror-backed hemisphere, by virtue of the satellite spin, acts essentially as an isolated sphere in space with respect to the radiation currents.

The temperature of each thin, silver, hemispherical bolometer is measured by a glass-coated bead thermistor mounted in close thermal contact with the hemisphere. Provision is also made to measure the temperatures of the mirrors in order to account for any heat lost by conduction through the hemisphere mounting posts.

Two of the hemispheres are coated black and thus respond about equally to solar and terrestrial radiation. Another hemisphere, coated white, is more sensitive to terrestrial than to solar radiation. A fourth hemisphere has a gold metal surface that makes it more sensitive to solar than to terrestrial radiation. Mounted at the top of the satellite axis is a black sphere to permit determination of any deterioration in the mirror surfaces by comparison with the blackened, mirror-backed hemispheres. Finally, a small hemisphere, specially coated to measure only short wavelengths and equipped with a shade to protect it from direct sunlight, was included to measure reflected sunlight

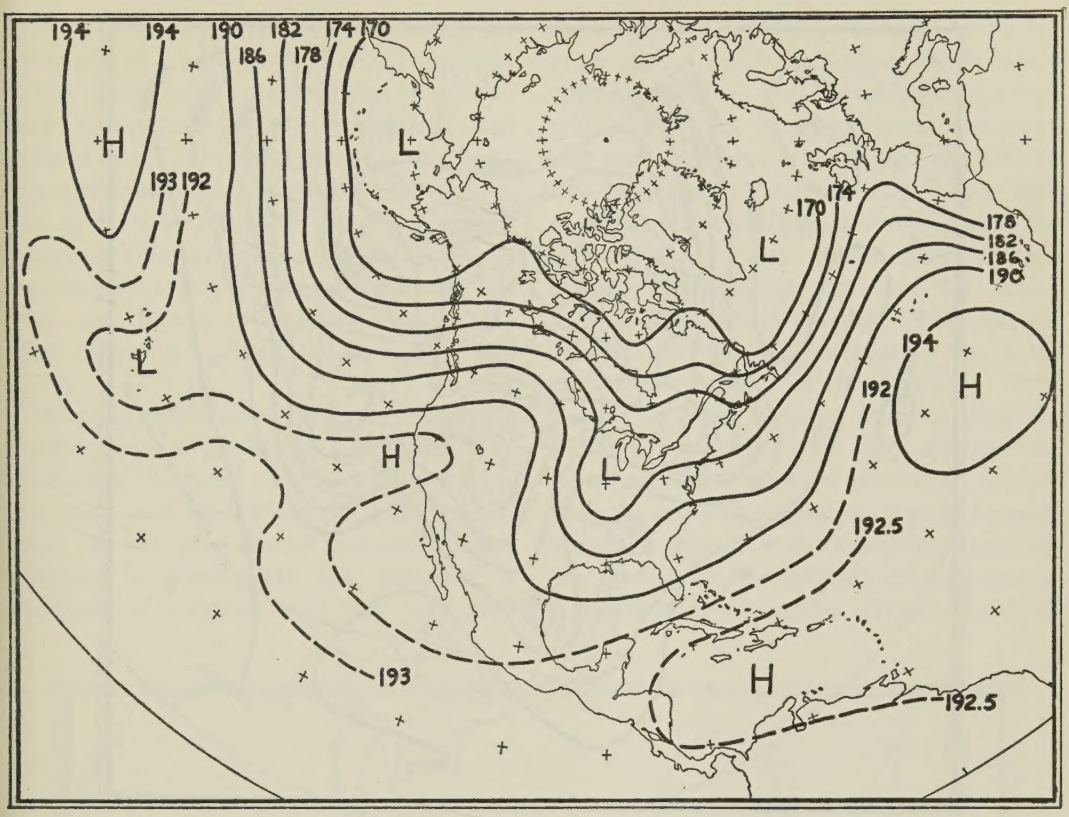


Fig. 4. *Height of 500-millibar Surface over Part of Northern Hemisphere, December 2, 1959, at 0000 UT. Heights equal values shown × 100 feet. (Compare with Fig. 2.)*

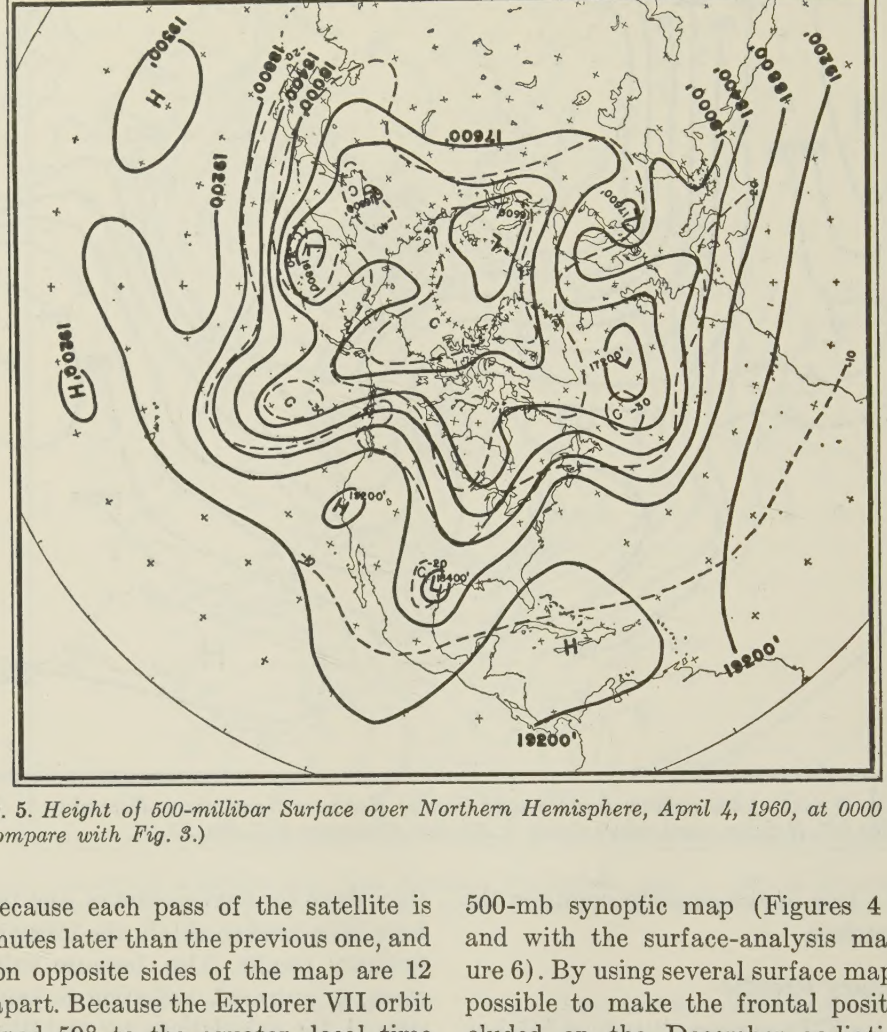
when the axis of the satellite points to the earth's surface.

Preliminary Results

Explorer VII's perigee altitude of 555 km, normally keeps it well above the F-2 layer of the ionosphere when in daylight and above the F layer when in the earth's shadow. The satellite's transmitter operated at 19.995 mc, and the quality of the received signal had a marked day-night variation. On the night side of the earth, useful signals could be received for 15 to 20 minutes, or more, while the satellite travelled over an orbital arc up to 1/5 the distance around the earth. On the sunlit side, however, where the ionosphere is less transparent to radio waves, useful signals were received over only about 1/2 to 2/3 this distance. Thus, the data collected for nighttime hours gives more extensive coverage than those for daytime hours, and therefore have been used to obtain the following preliminary results. Also, because only long-wave, or infrared, radiation is being considered, the calculations for nighttime data are much simpler.

The radius of the circle of coverage of Explorer VII's radiation sensors is roughly 23° of equatorial latitude (about 2500 km) at perigee and 31.5° (about 3500 km) at apogee. However, half the radiation power is received from an area below the satellite with a radius of only 5.3° of equatorial latitude (595 km) at perigee and 9° (1015 km) at apogee.

Figures 2 and 3 show the long-wave radiation loss measured by Explorer VII for the night of December 2, 1959, and for the night of April 4, 1960. Each dot along the orbital path represents one observation. The map cannot be given a specific synoptic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west of Hawaii definitely establishes another low at about 10°N. For the segment of the orbital path between these two, however, the data are not as complete, and while a trend toward a low value is shown, it is not certain, as the map indicates, that this is in fact the same large-scale low-radiation area. There is a general eastward movement of this outgoing radiation cell from map to map, in agreement with the wind direction at high levels during this season.

Despite uncertainties in the analysis, there appears to be a clear indication that large-scale patterns of outward radiation flux exist, and that these patterns are related to the large-scale features of the weather. Meteorologists had expected a variation of outgoing radiation with latitude, but the preliminary results show variation of the outgoing long-wave radiation with longitude as well. In addition, the suggestion by C-G. Rossby several years ago that radiation loss is controlled by circulation patterns is clearly verified. It is also apparent that these results re-emphasize the important role that clouds play in controlling the outgoing radiation. The accuracy of estimates of outgoing radiation will be governed to a large extent by the accuracy of the estimate of cloud cover.

It is of some interest to note that the radiation gradient with latitude for the April radiation map is somewhat steeper than the latitudinal gradient for the December maps. Also, the heat loss from the northern portion of the orbital belt is lower in April than in December. Thus, the April

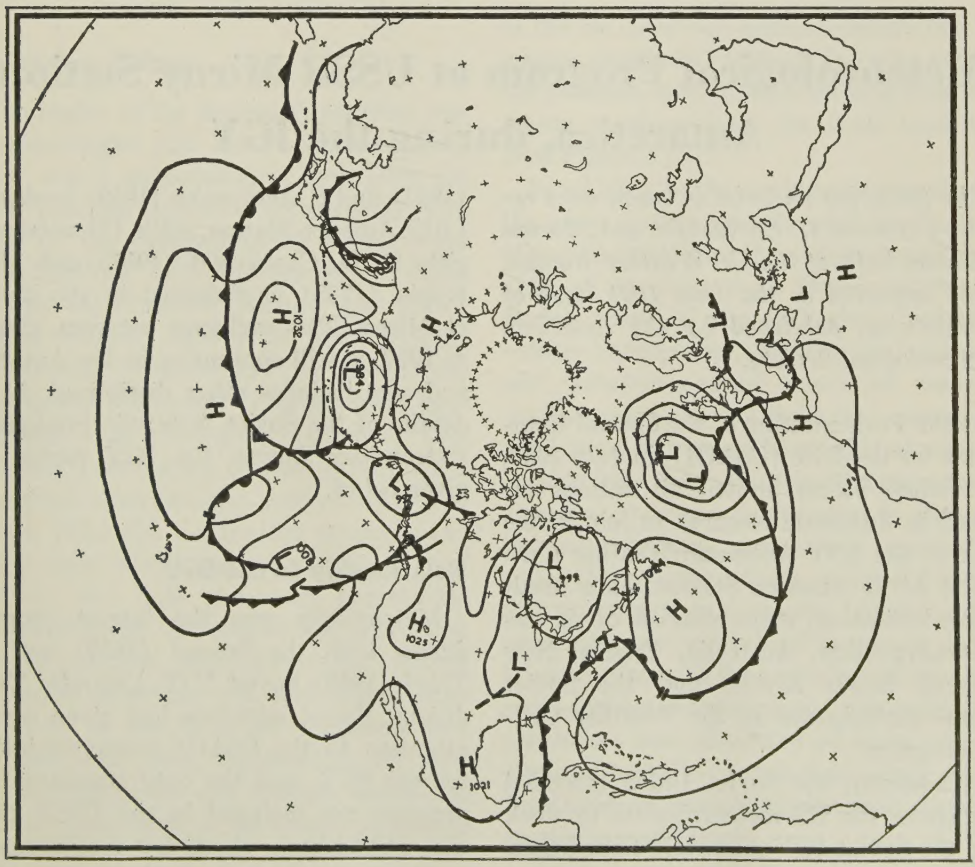

Fig. 6. *Analysis of Surface Weather in the Northern Hemisphere, April 4, 1960, at 1200 UT. Fronts and centers of high (H) and low (L) pressure are shown. (Compare with Figs. 3 and 5.)*

radiation pattern looks more like a winter situation than that for December. Inspection of the 500-mb charts shows that this apparent anomaly is explainable, however, since the north-south temperature gradient is steeper on the April map, and the temperature at the northern border is significantly lower as well.

Conclusion

The radiation charts discussed above represent only the beginning of analysis of an enormous amount of data. Also, they treat only half of the problem—the radiation losses. Equally important to our understanding of the earth's heat budget are the radiation gains from the sun. These are being treated in continuing studies.

It appears from the preliminary results, that very useful radiation data can be collected using a modestly instrumented earth satellite. Inclusion of a data-storage unit, as in Tiros III (see *Bulletin No. 51*), so that the measurements for a complete orbit may be obtained by a ground station, makes possible the construction of radiation maps for the whole earth. The problem of analysis is thus made simpler, moreover, as it is no longer necessary to attempt to form a comprehensive picture by fitting together many pieces of scattered data. Instead, data are continuous and a comprehensive view of the earth's radiation balance can be more-readily obtained.

Meteorological Program at USSR Mirny Station, Antarctica, during the IGY

The following material is based on a report by Gordon D. Cartwright and Morton J. Rubin, both of the US Weather Bureau, which appeared in the June 1961 issue of Weatherwise, *published by the American Meteorological Society.*

At the Paris meeting of the Special Committee for the IGY (CSAGI), in July 1955, the United States invited all nations involved in Antarctic research to join in the work of the IGY Antarctic Weather Central at Little America Station. As a result of this invitation, meteorologists of six nations—Argentina, Australia, France, New Zealand, South Africa, and the Soviet Union—participated in the Weather Central program.

In addition, the Soviet Union extended invitations for US meteorologists to work with the Soviet IGY Antarctic Expeditions based at Mirny Station. During 1957 and 1958, Soviet Meteorologists V. I. Rastorguev (1957) and P. Astapenko (1958) worked at Little America Station, while US meteorologists G. D. Cartwright (1957) and M. J. Rubin (1958) participated in the studies at Mirny. This exchange program, started in 1957, is still continuing in the Antarctic and also includes other disciplines. A few details of the Soviet Antarctic program in meteorology during the IGY period are given below.

Relationship to the IGY

Meteorology was the largest program during both the Second (1957) and the Third (1958) Soviet IGY Antarctic Expeditions. Soviet scientists had given careful attention to the CSAGI recommendations for the IGY, and the only standard IGY program not included in the USSR effort was atmospheric chemistry measurements (carbon dioxide and particulate matter). Glaciology, another large program, was

closely coordinated with meteorology. Frequent scientific meetings held during the winter helped stimulate interest in these interdisciplinary relationships. There was also full awareness of the interdependence of data taken by all countries working in the Antarctic, and intense interest was shown in the findings at other stations.

Of the USSR stations (see Table 1), Mirny, Oasis, and Vostok had the most consistent and most complete meteorological programs. Since the IGY, the following changes have taken place with respect to Soviet Antarctic Stations: Vostok-I was replaced by Vostok; Oasis, Pioneerskaya, and Sovietskaya have been discontinued; and Komsomolskaya has operated since early 1959 only as a summertime station. (The Lazarev station, at 69°58′S, 12°55′E, elevation 24 m, on the Princess Astrid Coast, was established on March 10, 1959.)

Program at Mirny

The leader of the Second Expedition was an oceanologist and the Third Expedition leader was a meteorologist; both gave the fullest possible support to meteorology. The heads of the meteorological groups were Oskar Krichak* (Forecast Institute of Moscow) for the Second Expedition and Viktor Bugaev (former director of the Tashkent Geophysical Observatory) for the Third. Each group was made up of several "synopticians," meteorologists (physical meteorology), aerologists (including specialists in aircraft observations), and ordinary observers (who did the routine synoptic and hourly observations and reporting).

Mirny was both the main operational headquarters for the continental expedition and its principal scientific station. About 190 Soviet scientists and technicians wintered over on the Antarctic Continent during 1957 and 1958, representing all geophysical disciplines and biology. About 125 of these spent most of the winter in Mirny, at the edge of the continental ice sheet and just on the Antarctic Circle. The base was set up at a point on the Davis Sea where small rounded rocky outcrops keep the ice sheet immobile. Some buildings were actually sited on rock, others on the ice shelf. At the meteorological station, the gradient of the ice sheet was about 3 meters per 100 meters downward toward the sea, and all the principal instrumental installations were placed up-slope from the main buildings. (See Figure 7.)

Table 1. *Station Data for USSR Antarctic IGY Stations*

Station	Location	Height(m)
Mirny	66°33′S, 93°01′E	35
Oasis	66°16′S, 100°45′E	29
Pioneerskaya	69°44′S, 95°30′E	2700
Vostok-I	72°08′S, 96°35′E	3140
Vostok	78°27′S, 106°52′E	3420
Sovietskaya	78°24′S, 87°35′E	3570
Komsomolskaya	74°05′S, 97°29′E	3420

In addition to the rawinsonde ascents and the usual surface synoptic and hourly (aviation) observations, the meteorological program at the three main Soviet stations included most of the following: radiation —total-hemispheric, diffuse, and direct— and radiation balance (net), all recorded continuously on multichannel recorders; wind, temperature, and humidity at selected heights from the surface to 10 meters (these were not continuously recorded in all cases, but observations were made regularly); sub-surface temperatures at closely spaced intervals down to 4 meters (similar measurements were carried out to greater depths in connection with the glaciological studies); snow-surface maximum and minimum temperatures; and collection of snow crystals (intermittently). Aerological observations from aircraft were among the special studies carried out at Mirny.

Table 2 gives average climatological data for Mirny for the years 1956–1958.

* Krichak and seven other men lost their lives in a fire at Mirny Station on August 3, 1960.

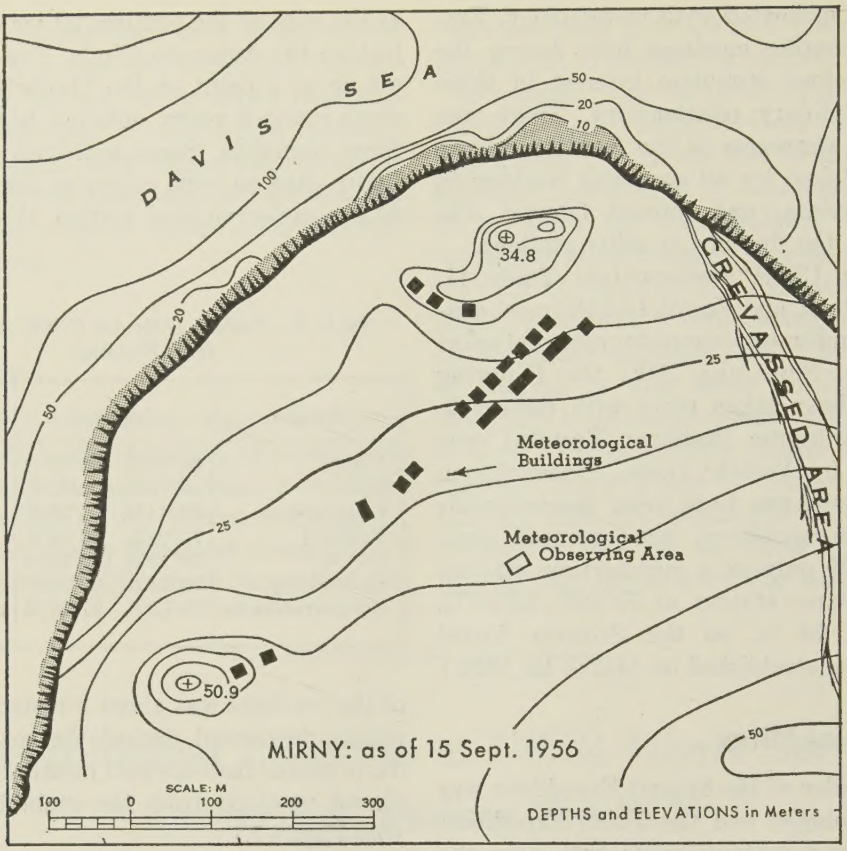

Fig. 7. *Physical Setting of USSR Mirny IGY Station.*

Airborne Meteorological Program

The airborne meteorological program was extensive. A two-engine aircraft was fitted out as a flying meteorological observatory to measure and record solar radiation; cloud density (optical measurements); total solar and sky radiation; reflected solar radiation; pressure, temperature, and relative humidity; air temperature; altitude; ice-crystal and cloud-drop samples; cloud forms; and surface phenomena.

On several occasions, equipment for measuring atmospheric-electricity phenomena was placed aboard and flights were carried out over the ocean, over the continental ice-cap, and through low- and middle-level clouds. The plane was also fitted with a mount for a vertically-oriented mapping camera.

In 10 months during 1958, seventeen flights were made, usually with three observers aboard to attend to the instruments and to record the necessary data. Vertical soundings were made as the plane flew its course for distances usually ranging from 100 km over the ocean to 500 km or further over the continental regions. On a meteorological reconnaissance flight over the site of Vostok-I (April 22, 1958), 3140 meters above sea level, it was determined that the temperature was —52°C (—61.6°F) only 23 meters above the surface, while the temperature at 200 meters was —36°C (—32.8°F). The surface inversion was marked by a very thin ice-crystal fog—perhaps produced by the presence of the airplane, although the thin fog had been observed before the plane descended into the inversion—and the snow surface was somewhat obscured.

In other portions of the flight, it was

noted that the orientation of the primary sastrugi (snow-surface forms resulting from scouring and filling by the wind) reflected a prevailing surface wind from 110°, while a secondary orientation showed a wind from about 170°. In 1957, eight men wintered at the Vostok-I Station on their way to the geomagnetic pole and carried out a surface and upper-air observational program as well as glaciological observations. The mean temperature they recorded for June 1957 was —51.7°C (—61.1°F), the maximum was —30.5°C (—22.9°F), and the minimum was —67.8°C (—90.0°F).

Ice Reconnaissance Program

One of the unique programs carried out by both the Second and Third Soviet Antarctic expeditions was the regular monthly reconnaissance of the distribution of pack ice from the edge of continental ice to the edge of the pack ice, as much as 700 km from the base. This program was carried out by aircraft with special ice observers and meteorological observers on board. In some instances, the aircraft was also fitted with meteorographs to measure pressure, temperature, and relative humidity, and vertical soundings were made at the limit of flight over the sea.

Detailed and highly organized records of the character of the pack ice were kept by the ice observers, and these were compiled in the form of time analyses (monthly or bi-monthly) of ice features over the areas surveyed regularly by the aircraft. This information seemed to have an interesting correlation with the prevailing weather conditions and a preliminary analysis of these features was undertaken during the Expedition. It was tentatively postulated by the chief of the meteorological group that variations in the position of edge of the pack ice, as well as its character in the region off Mirny, showed the effects of the prevailing distribution of cyclones and anticyclones in this area.

Automatic Weather Stations

In November 1958, an automatic weather station, reporting wind, pressure, and temperature data, was established on Drygalski Island (65°43′S, 92°30′E), a 350-meter-high ice-dome over a submarine rise in the Davis Sea, some 75 km north of Mirny. The equipment transmitted air pressures over a 100-mb range, wind speeds from 1 to 16 meters per second, wind direction to 32 points, and temperatures from +5° to —88°C (+42.8 to —126.4°F).

On Drygalski Island, the sastrugi patterns showed that the prevailing winds were easterly. Orographically-induced low clouds and fog were common over the island. During the short period of occupation, 40-meter-per-second winds (90 mph) were experienced.

Earlier in the year, a similar automatic weather station had been hurriedly installed on the ice slope between Mirny and Pioneerskaya Stations during a glaciological traverse. The equipment soon ceased transmitting, however, probably as a result of mechanical failure induced by the strong katabatic (downslope) winds and drifting snow so common in the region.

Table 2. *Average Climatological Data: Mirny, 1956–1958*

Measurement	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mean Temp. (°C)	−0.9	−4.8	−9.3	−11.4	−13.2	−17.1	−16.3	−18.1	−16.6	−13.2	−7.2	−2.4	−10.9
Max. Temp. (°C)	+8	+3	−1	−1	0	−2	−4	−4	−2	−2	+5	+8	−8
Min. Temp. (°C)	−9	−19	−20	−26	−27	−33	−36	−40	−33	−32	−18	−11	−40
Prev. Wind Dir.	107°	130°	133°	130°	127°	150°	123°	147°	117°	103°	123°	100°	124°
Mean Speed (Kts.)	16.9	19.2	22.0	27.6	28.1	26.4	28.7	28.3	26.0	20.2	19.4	15.7	23.2
Max. Speed (Kts.)	56	49	54	62	78	76	99	99	89	78	54	58	99
No. Days >29 Kts.	9	14	18	22	26	20	27	24	20	20	14	7	224
Pressure (Mb)	985.6	986.2	982.1	982.8	988.8	991.2	984.2	980.8	977.0	979.7	982.9	986.9	984.0

The Program at Oasis

The Soviet station at Oasis was of particular importance because of the unusual topographic features in its vicinity. These included an extensive area of exposed rock, virtually snow-free during most of the year and contiguous to a configuration of the continental ice sheet that produced especially strong winds under certain synoptic pressure distributions. The freezing and thawing of fresh-water lakes formed by the melt water from the continental ice sheet afforded a very interesting laboratory for study of the effects of seasonal radiation changes on the ice regime.

A full program of radiation measurements in various parts of the Oasis area was pursued by a small staff of six men. Soil temperature measurements at a number of depths also provided important data for the study of heat transfer to and from the fresh-water lakes and morainic material (mostly unsorted, glacier-deposited rock debris) that comprised most of the Oasis area. These programs were of particular interest in glaciological studies as well as in studies of frozen ground.

Climatic Conditions

Generally, temperature at Mirny (Table 2) is relatively mild for Antarctica, excluding the Palmer Peninsula. However, the relatively high frequency of strong winds makes difficult the task of meteorological observers and others who have to be out-of-doors. During the winter of 1958, there were 13 days with wind force above 60 knots. On one such occasion (July 23, 1958) the pressure fell 21 mb in six hours, and 36 mb in 24 hours. Safety lines were strung from meteorological headquarters to the observing site, some 200 meters upwind; later, lines were installed around the camp after two incidents in which men lost their way within the confines of the camp during blizzards.

The prevailing wind was between east and southeast, at an angle of about 30° to the main slope of the ice sheet; this also was the direction of the strongest winds, which appear to result from the eastward passage of storm centers north of the station and the reinforcement of the gradient winds (horizontal winds tangent to constant-pressure-surface contours) by the katabatic effect. The use of a balloon-release tower greatly increased the number of successful launchings (only two observations were missed in two years because of hurricane force winds) even though some occasions required the launching of as many as four balloons before one was successful.

Stations on the high ice-dome, such as Vostok (see Table 3 for climatological data), Komsomolskaya, and Sovietskaya, were not bothered much by drifting snow as were the coastal and ice-slope stations. At the inland stations, difficulties arose from, and were associated with, high altitude and low temperatures that severely restricted strong and prolonged outdoor physical activities, and from long hours and months of darkness. Balloons for pilot and raob (radiosonde observation) ascents failed prematurely because of the low temperatures encountered from the surface to the stratosphere, although preconditioning the balloons with heat and diesel-fuel baths helped somewhat.

At Pioneerskaya station, as at Mirny and Oasis to a lesser extent, the strong winds and drifting snow made impossible the determination of how much snow was falling and how much was drifting. Crude equipment for measuring drifting snow was imprecise, and snow gauges were useless; only measurements of net accumulation against arrays of stakes gave reliable figures anywhere.

Results of Special Programs

A number of special studies were carried out by the members of the Soviet Antarctic Expeditions. These were meant to point out the character of the meteorological processes in the region and to help throw light on some exchange processes in respect to

Table 3. *Average Climatological Data: Vostok, 1958*

Measurement	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mean Temp. (°C)	−31.3	−44.6	−55.9	−64.0	−62.9	−67.9	−65.3	−71.8	−66.3	−58.8	−43.2	−33.4	−55.4
Max. Temp. (°C)	−23	−29	−47	−43	−43	−47	−44	−55	−45	−41	−34	−26	−23
Min. Temp. (°C)	−41	−60	−67	−73	−78	−80.7	−81	−87.4*	−82	−71	−60	−44	−87.4*
Prev. Wind Dir.	180°	180°	220°	240°	240°	270°	240°	220°	250°	220°	220°	260°	228°
Mean Speed (Kts.)	8.9	7.2	9.9	7.8	10.1	9.5	9.7	9.1	10.5	27.8	8.1	7.4	8.9
Max. Speed (Kts.)	27	18	19	19	29	49	25	25	25		25	21	49
No. Days >29 Kts.	0	0	0	0	1	1	0	0	0	0	0	0	2
Pressure (Mb)	630.0	627.6	624.8	628.0	627.7	623.1	623.2	614.3	613.7	620.2	624.0	626.5	623.6

* World record minimum air temperature (−125.3°F), recorded August 25, 1958. On August 24, 1960, a new record minimum of −88.3°C (−126.9°F) was recorded.

the atmosphere-ocean-ice complex. Synoptic and climatological analyses, as well as the study of regional features, radiation balance, ice-mass movement, katabatic winds, and turbulent exchanges, have been reported on by Soviet Antarctic scientists. In general, they are similar to programs carried out by other countries. Two special studies, however, appear to be unique to the Soviet expedition—an airborne radiation program extending over a period of several years, and an airborne study of the atmospheric electrical field, carried out in 1958.

The airborne radiation program provided data for determining the short-wave radiation balance in the troposophere, the albedo of the underlying surface of the continental ice and the Davis Sea, and the albedo of clouds. Summertime mean values of atmospheric heating due to absorption of solar radiation were as shown in Table 4. Computations of cooling in the free atmosphere due to radiation under clear conditions gave about the same order of values as the radiative heating.

From the airplane observations, the mean value of the albedo of the ice slope was found to be 80% for sun heights of 25–35°; the albedo decreased as the solar altitude decreased, probably owing to snow sastrugi that shade the surface when the sun is low. The mean albedo of young sea ice was found to be 65%. Albedo of the open sea varied with roughness: in calm conditions with a sun height of 10°, the albedo was 33%; with small waves and sun height of 30°, it was 11%. The mean albedo of stratocumulus clouds, the most frequently observed cloud form over the sea, was 62%. Altocumulus clouds with a thickness of 250–300 meters had an albedo of 60%, while altostratus clouds, which predominate over the ice slope, had an average albedo of 40–60%.

Studies of the gradient of the earth's atmospheric electric field when pressure systems were over the ocean showed that the potential gradient is increased in the leading portion of a cyclone and in the rear of an anticyclone, and is decreased in the rear of a cyclone and in the leading portion of an anticyclone. Presumably, this is explained by the regime of vertical motions in the pressure systems. Middle- and upper-level clouds do not appear to affect the potential gradient, but lower clouds tend to decrease it by as much as 30%. On the continental surface itself, the principal variations in potential gradient result from wind conditions and cloudiness and include the monthly and annual variations. When wind speed increased from 10 to 70 knots, for example, the positive value of the gradient increased, but at wind speeds greater than 70 knots,

Table 4. *Summertime Mean Values of Atmospheric Heating, at Heights to 4 km, by Absorption of Solar Radiation.*

Surface	100 m–2 km	2–4 km
Open sea	0.034°C/hr	0.026°C/hr
Young sea ice	0.023°C/hr	0.010°C/hr
Continental ice-slope	—	0.033°C/hr

the potential gradient changed sharply in sign and value, reaching negative values of tens of thousands of volts per meter.

Large positive and negative values of space-charge density noted were several times greater than the space charges observed, in thunderstorms, elsewhere in the world. The sign of the space charge depended mainly on wind velocity, with large negative values observed at wind speeds above 70 knots. It was also noted that the current from sharp points during snowstorms tends to reduce the negative charge of the earth; this is contrary to measurements obtained from other continental regions, but supports data from Cambridge, England, for stormy periods.

Meteorological Rockets

A few meteorological rocket soundings were made from the Soviet research vessel *Ob* during the 1957–58 supply season. Two of these were made at Mirny and others were at points around the periphery of East Antarctica and the Indian Ocean. These rockets reached heights of about 50 km (31 mi) and provided temperature, pressure, and wind data from the middle stratosphere.

Conclusion

The highlights described above illustrate the comprehensive and detailed character of the Soviet meteorology program in the Antarctic. The US scientists who worked at Mirny experienced effective working relationships and cordial personal associations with their Soviet colleagues during the periods of their individual assignments there. They found it both an interesting and rewarding experience that gave them a better understanding of Soviet science and scientists.

Explorer XIII Micrometeoroid Satellite

Explorer XIII (1961 Chi) was launched from NASA's Wallops Island Station, Virginia, at 2:29 pm EDT, August 25, 1961. The satellite carried five different types of micrometeoroid detectors designed to record and send back to earth information about the characteristics of micrometeoroids and their potential hazards to future spaceflight. The launch also served as a test of the performance, structural integrity, and environmental conditions of the all-solid-fuel, four-stage Scout launch vehicle and its guidance control system.

The planned orbit of the satellite was between 280 and 610 statute miles above the earth. While preliminary orbital calculations suggested that a stable orbit had been achieved, later data indicated an unexpectedly low perigee of 74 statute miles, resulting in the short lifetime for the satellite of 2½ days. During this interval, Explorer XIII transmitted 13 minutes (73,980 "bits") of data. The satellite re-entered the earth's atmosphere after a final transmission over Antofagasta, Chile, at 0200 UT, August 28, 1961. Orbital data were as follows: period, 97.5 minutes; apogee, 722 statute miles; perigee, 74 statute miles; and inclination, 37.7°.

Scout Launch Vehicle

The 72-foot, 36,600-lb, Scout launch vehicle, under development by the NASA Langley Research Center since mid-1958, is designed to provide the United States with a small, reliable, and flexible solid-fuel booster rocket for space-probe and orbital missions. (A description of the rocket appears in *Bulletin No. 46*.)

Early reports following the launch of Explorer XIII indicated that all stages of

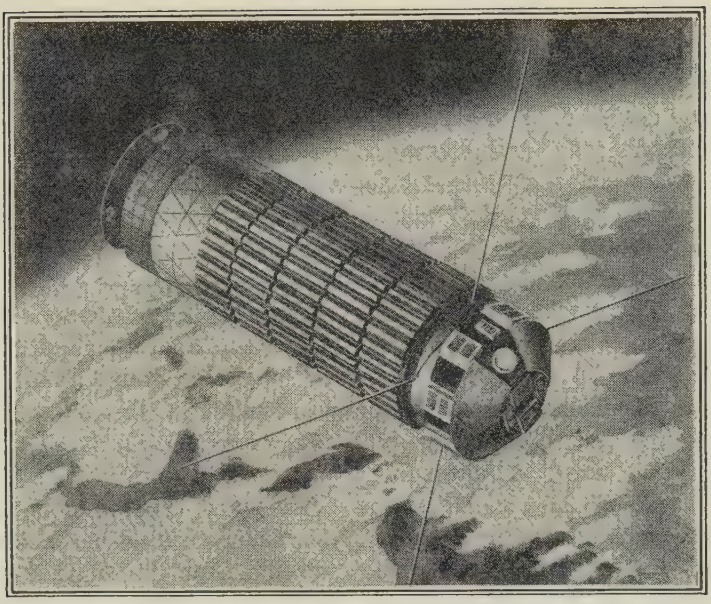

Fig. 8. *Explorer XIII Micrometeoroid Satellite. Satellite structure is built around fourth-stage rocket. Five rows of cylinders around central portion are pressurized-cell detectors; triangles below them are grid detectors; squares near base are wire detectors. Larger blocks in nose and around forward portion of satellite are cadmium-sulphide impact detectors and smaller blocks in same areas are silicon solar cells. Dark trapezoidal area on nose, with circular window, is an impact sensor. NASA drawing.*

the Scout vehicle performed as predicted, except for a pitch-up of the fourth stage at injection. It is believed that this deviation from expected performance caused the very low perigee responsible for the early demise of the satellite.

Payload Description

Explorer XIII was cylindrical in shape, about 24 inches in diameter, and approximately 76 inches long. The experimental equipment was built around the 18-inch-diameter, 72-inch-long fourth-stage of the Scout vehicle. A thin heat shield that protected the satellite during its ascent was later jettisoned into space, exposing the highly sensitive micrometeoroid detectors. (See Figure 8.)

Total weight of the satellite payload, including the various sensors, other scientific equipment, and mounting hardware, was about 127 lbs. Added to this were the fourth-stage rocket, the upper transition section connecting the fourth stage to the third stage, and the spent spin motors, weighing a total of 63 lbs, for a total weight in orbit of nearly 190 lbs.

Micrometeoroid Experiments

Meteoroids, composed of iron, silicates, and other substances, are more numerous in interplanetary space than previously believed, and may impact a satellite at velocities ranging from 7–45 miles per second. Meteoroids usually burn as they fall through the atmosphere, and are then termed *meteors.* Those reaching the earth are *meteorites.* It is believed that several thousand tons of minute meteorites (micrometeorites, or micrometeoritic dust) may settle to the earth each day.

Meteoroids may be derived from the asteroids, which revolve about the sun in orbits between Mars and Jupiter. Those in elliptical orbits periodically cross the earth's path, and may impact on the earth or moon. Meteoroids may also be derived from comets, which revolve in highly eccentric orbits

around the sun and frequently approach relatively close to the earth.

The micrometeoroid detectors aboard Explorer XIII were designed to measure directly the puncture hazard to the structural skin of a spacecraft; micrometeoroid flux rates; and the erosion of spacecraft materials by small particles in space; and to record information affecting the design of solar cells for spacecraft power that would be more resistant to damage by particles and radiations in space.

The five types of detectors carried by the satellite (Fig. 8) included pressurized cells, foil gauges, and wire grids, providing a total surface area of 24¼ square feet exposed to micrometeoroid penetration; for impact detection, the satellite carried cadmium-sulphide cells and impact sensors having a combined total surface area of four square feet. Five groups of shingled, window-like silicon solar cells were placed on the nose of the satellite to determine, for future space experiments, the amount of protection such cells require. Two of these groups of solar cells were unprotected, 6-mil-thick glass slides covered the sensitive areas of two other groups of cells, and one group was protected by a 62-mil-thick quartz window.

Temperature measurements were made at selected places throughout the satellite, and a telemeter system with erectable antennas was located in the nose section to transmit data to ground receiving stations.

Despite Explorer XIII's short lifetime in orbit, some data were obtained from the micrometeoroid experiments aboard the satellite. Analysis of this data, conducted at NASA's Langley Research Center, may produce useful information on micrometeoroid hazards in the space around the earth.

World Warning Agency Report

Solar-Terrestrial Activity: January 1 - June 30, 1961

The following report, one of a series published periodically during and since the IGY/IGC period, is based on material issued by the World Warning Agency (AGIWARN), Fort Belvoir, Virginia, and on compilations of Solar-Geophysical Data *issued by the Central Radio Propagation Laboratories (CRPL), Boulder, Colorado. Both AGIWARN and CRPL are administered by the US National Bureau of Standards.*

A World Warning Agency report for the final quarter of 1960 appeared in Bulletin No. 47, *which also contained a report on the new plan for Geophysical Alerts and Special World Intervals (SWI) developed for use during 1961–1962.*

January 1—March 13, 1961

Of eight geomagnetic disturbances recorded by AGIWARN during the first quarter of 1961, five were sufficiently severe to warrant the issuance of World-wide Geophysical Alerts. Of these, Advance Alerts could be distributed effectively for only three; for the remaining five storms, lack of severity and unusual time of occurrence of the first K-figure of 5 or greater were the limiting factors. (The K-figure measures storm intensity on a scale of 0 to 9.) There were no major solar flares (class 3 or 3+) during the first quarter of 1961.

In terms of geomagnetic activity, none of the disturbances during this period could be classified as severe. However, associated with the eight magnetic storms that occurred in the 72-day period covered by this report were 16 days in which the magnetic field was disturbed and 23 days evaluated as unstable in terms of whole-day radio-quality indices.

The considerable amount of radio disturbance has resulted in deep concern over the growing problem of effective geomagnetic-storm prediction in this declining phase of the sunspot cycle. AGIWARN's experience in geomagnetic-storm prediction has shown that magnetically significant storms generally lend themselves to prediction more readily than minor storms. Major storms are often preceded by either observable solar activity of some nature or by a well-established pattern of recurrence at regular intervals.

The geomagnetic storms recorded in the first quarter of 1961 belong in the minor-storm category, and generally were not preceded by either of these major-storm indications. In fact, solar activity of the "event-type," observed so regularly during sunspot maximum and succeeding months, was practically non-existent during this interval. Consequently, anticipation of these storms through application of existing prediction techniques was generally not possible. Moreover, apparently anomolous characteristics of most of the storms—sudden commencements, lack of continuity, considerable variation in duration, etc.—greatly complicated post-storm analysis.

March 14—June 30, 1961

Four major solar flares occurred during the second quarter of 1961. Thirteen geomagnetic disturbances were recorded by AGIWARN in this interval, and Worldwide Geophysical Alerts were issued for all but four. Of these, only two were classified as severe (storm A-index of about 50 or greater, on a scale of 0–400). Advance Geophysical Alerts were issued for four of the 13 storms, including both of the severe storms. Cosmic-ray and radio-disturbance effects associated with the severe storm of April 13 are shown in Figures 9 and 10.

Magnetic activity followed the general pattern to be expected in this declining portion of the sunspot cycle. During solar-quiet periods, most storms began gradually

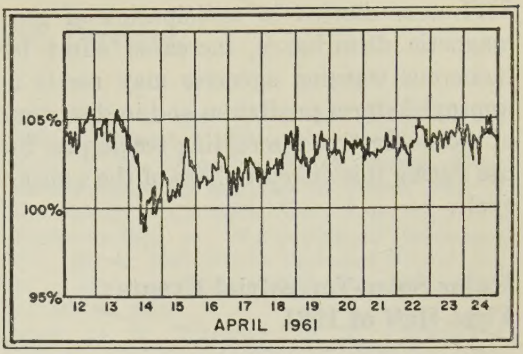

Fig. 9. *Cosmic-Ray Indices for Mid-April 1961, Showing Forbush Decrease Associated with the Severe Magnetic Disturbances Beginning on April 13. From records of Deep River, Canada, neutron monitor.*

and were of minor intensity. During active solar periods, the storms began suddenly, were associated with some particular event on the sun, and were of severe intensity.

The new plan for predicting intervals during which severe geomagnetic disturbance is expected (see *Bulletin No. 47*) was employed during this quarter. A predicted Special World Interval was declared once; although a storm subsequently began, it did not reach a severe level of intensity.

The new plan for Geophysical Alerts and SWI is coordinated through the International World Day Service. While the plan is similar to the IGY plan, under which

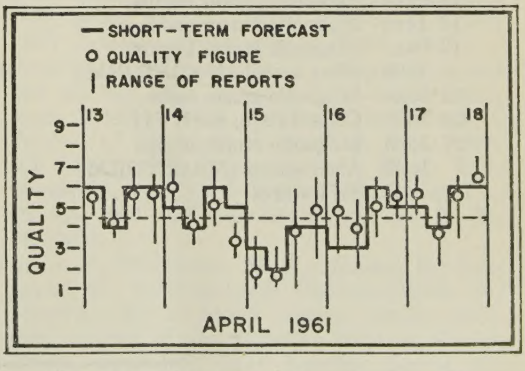

Fig. 10. *Radio-Propagation Quality Figures for Mid-April 1961, Showing Radio Disturbance in North Atlantic Area Associated with Severe Magnetic Storm Beginning on April 13. Prepared by CRPL, National Bureau of Standards.*

SWI were started in anticipation of geomagnetic disturbance, increased effort by numerous warning agencies may result in improved storm prediction and in discovery of more-effective forecasting techniques for use during this difficult phase of the sunspot cycle.

Major Solar-Terrestrial Events: First Half of 1961

The following is a list of major solar flares; geomagnetic disturbances; and World-wide Geophysical Alerts and SWI during the period January 1–June 30, 1961:

Jan	8	1618	Magnetic storm begins
	10	00xx*	Magnetic storm ends
	19	15xx	Magnetic storm begins
	20	1600	Alert issued (MAGSTORM)**
		19xx	Magnetic storm ends
Feb	3	0908	Magnetic storm begins
		23xx	Magnetic storm ends
	4	1330	Magnetic storm begins
		1600	Alert issued (MAGSTORM)
	7	01xx	Magnetic storm ends
	13	07xx	Magnetic storm begins
	14	01xx	Magnetic storm ends
	16	0044	Magnetic storm begins
		1600	Alert issued (MAGSTORM)
	22	11xx	Magnetic storm ends
Mar	5	21xx	Magnetic storm begins
	6	14xx	Magnetic storm ends
		1600	Alert issued (MAGSTORM) SWI starts †
	7	2359	SWI finishes
	9	1327	Magnetic storm begins
	10	13xx	Magnetic storm ends
		1600	Alert issued (MAGSTORM)
	14	0115	Magnetic storm begins
	16	14xx	Magnetic storm ends
	19	04xx	Magnetic storm begins
		1600	Alert issued (MAGSTORM)
	21	00xx	Magnetic storm ends
	26	1009	Class 3 flare; S-SWF††
	27	1505	Magnetic storm begins
		1600	Alert issued (MAGSTORM) SWI starts
	28	11xx	Magnetic storm ends
		2359	SWI finishes
	31	1338	Magnetic storm begins
Apr	1	13xx	Magnetic storm ends
	2	20xx	Magnetic storm begins
	3	12xx	Magnetic storm ends
		1600	Alert issued (MAGSTORM)
	9	07xx	Magnetic storm begins
		1600	Alert issued (MAGSTORM)
		17xx	Magnetic storm ends
	13	1452	Severe magnetic storm begins
	14	1600	Alert issued (MAGSTORM)
	16	06xx	Severe magnetic storm ends
	26	1646	Class 3 flare; Slow S-SWF
May	4	2145	Class 3 flare; Slow S-SWF
	6	05xx	Magnetic storm begins
		1600	Alert issued PREDICTED SWI starts
	7	16xx	Magnetic storm ends
		2359	PREDICTED SWI finishes
	9	1438	Class 3 flare
	16	01xx	Magnetic storm begins
	17	02xx	Magnetic storm ends
	24	23xx	Magnetic storm begins
	25	1600	Alert issued (MAGSTORM)
	26	04xx	Magnetic storm ends
	31	01xx	Magnetic storm begins
Jun	1	1600	Alert issued (MAGSTORM)
	2	18xx	Magnetic storm ends
	20	18xx	Severe magnetic storm begins
	21	1600	Alert issued (MAGSTORM)
	23	03xx	Severe magnetic storm ends
	29	0011	Magnetic storm begins
		12xx	Magnetic storm ends
		1600	Alert issued (MAGSTORM)

* "xx" indicates gradual beginning or ending of a disturbance, following the hour indicated, such that the precise moment could not be determined.

** No ending times for Alerts are issued; this is left to the discretion of the individual observatories. Capitalized acronyms indicate the kind of Alert issued, i.e., MAGSTORM = magnetic storm; COSRAY = cosmic ray; SOFLARE = solar flare; etc.

† SWI's start at the time the associated Alert is issued (1600 UT) and finish at the end of the day indicated (2359 UT); PREDICTED SWI's are based on the prediction that important geomagnetic and associated activity will begin in a few hours.

†† S-SWF = sudden short-wave fadeout and gradual recovery; Slow S-SWF = slow short-wave fadeout (taking 5–15 minutes) and gradual recovery.

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Annals of the International Geophysical Year

A complete listing of volumes of the IGY *Annals* published or in preparation at that time appeared in *Bulletin No. 28,* October 1959. The following supplementary list brings the earlier list up to date, including correction of several titles:

Vol. IIA, "The International Geophysical Year Meetings," 395 p., 1959.

Vol. IIB, "The International Geophysical Year Meetings," p. 397–709, 1959.

Vol. IX, "The Membership and Programs of the IGY Participating Committees," 307 p., 1959.

Vol. X, "The Fifth Meeting and the Termination of CSAGI," 288 p., 1960.

Vol. XI, In preparation (will include papers presented at the Fifth Meeting of CSAGI other than those on rocket and satellite results, which are published in Vol. XII).

Vol. XII, "First Results of IGY Rocket and Satellite Research," Part 1, 459 p., 1960. Part 2, p. 460–935, 1961.

Vol. XIII, "IGY Ionospheric Tables," 643 p., 1961.

Vol. XIV, "IGY Ionospheric Tables," 545 p., 1961.

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